Fattening rate of bluefin tuna *Thunnus thynnus* in two Mediterranean fish farms

by

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ABSTRACT. - Fish size and proximate composition were measured during the fattening process of two groups of bluefin tuna (*Thunnus thynnus*) kept in ocean cages in the southwestern Mediterranean Sea. The fish were first sampled just after capture in June 1998, and twice more over a month period at the two tuna farms located near Cabo Tiñoso in Murcia, Spain. Both groups were caught within 200 km of each other by purse seining during June. The results found that the mean of tuna fork lengths were significantly different among the three periods sampled, but not so between farms. Additionally, weight is significantly different over time. However, fat content was found to be significantly different between farms and increased from June to November at both locations. Variations in fat levels between both locations could be due to multiples reasons, such as different environmental conditions, feeding protocol or fish density.

RÉSUMÉ. - Taux d'engraissement du thon rouge *Thunnus thynnus* dans deux fermes aquacoles de Méditerranée.

La taille et la composition globale du thon rouge (*Thunnus thynnus*) ont été mesurées durant le processus d'engraissement en cage en Méditerranée sud-occidentale. Les poissons ont été capturés par seine à deux endroits distants de 200 km en juin 1998 et transportés à Cabo Tiñoso (Murcie, Espagne), où ils ont été stockés dans deux fermes aquacoles. Les individus ont été échantillonnés juste après leur capture en juin, et à deux occasions pendant le processus d'engraissement (juin et septembre). Les résultats ont montré que la moyenne des longueurs à la fourche était sensiblement différente entre les trois périodes. Le poids moyen a changé significativement dans le temps. Cependant, la teneur en graisse s'est avérée significativement différente entre les fermes et a augmenté de juin à novembre dans les deux sites. Les variations des niveaux de graisse entre les deux sites pourraient être dues à des raisons multiples, comme des conditions environnementales, un protocole d'alimentation ou une densité des poissons différents.

Key words. - Thunidae - *Thunnus thynnus* - MED - Bluefin tuna - Fattening process - Sea cages.

Tunas (Family Scombridae) have morpho-physiological adaptations that permit them to achieve a maximum metabolic rate that is more than double those of other active teleosts (Dewar and Graham, 1994; Brill *et al*., 2001). In addition, they have high rate of food assimilation and conversion, with the capacity to digest proteins three times faster than other fish (Graham, 1975; Stevens and McLeese, 1984). The capacity to grow quickly in a captive environment makes bluefin tuna (*Thunnus thynnus*) a profitable species for the commercial market and in particular the Japanese sashimi market (Itoh and Tsuji, 1996). The value of tuna is determined by its freshness, colour and fat content. The latest attribute is of primary importance when targeting market. Fat content depends on water temperature (higher in temperate water compared to tropical water), animal size (higher in big adults than in juveniles), sexual maturity (higher before spawning than after spawning)

At present, the southeast Spanish coast has become one of the target zones for the development of bluefin tuna fish farming. The bluefin tuna is caught by purse seining in the Mediterranean Sea, predominantly in June and July during the period of migration towards Mediterranean spawning grounds. The fish are then towed slowly back to the farm localities. On arrival in the farm area, the tuna are transferred through a connection between nets to static sea cages. Once accustomed to captivity, the fish fatten quickly and harvesting commences within three months of capture, at which point the animals are progressively removed from the cages.

Since 1995, the Murcia region has been a pioneer at raising captive bluefin tuna in the Mediterranean Sea. In 2002, six fattening cage farms were installed along 130 km of coast, most of them located in wave-exposed waters about 30 m depth. The annual regional production of bluefin oscillates between 4000 and 5000 tons. In spite of the high production, it remains a lack of understanding of the biological and environmental processes that influence the fattening rate of bluefin tuna farmed in the Mediterranean coast (Fushimi *et al*., 1998).

The general aim of this study was to compare the body composition of the bluefin tuna and its evolution throughout

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the fattening process in two tuna farms located in the Murcia region. Body size and composition (fat, protein and moisture) were analysed over a 6-month period for bluefin tuna at two commercial farms.

MATERIAL AND METHODS

Fattening process and sample collection

Fish were caught by purse seining during June 1998 in the western Mediterranean Sea. A total of 464 tunas were caught in Cabo de Palos and caged in Cabo Tiñoso north, 37º33'52''N-01º06'37''W (farm A). A total of 590 tunas were caught in Cabo de San Antonio and caged in Cabo Tiñoso South, 37º32'49''N-01º10'30''W (farm B) (Fig. 1). Farm A showed E-NE and SW currents parallel to the coast with high frequencies, during March. The strongest currents had maximum speeds of 16 cm/s in the SW direction, and an average speed of 3 cm/s. Farm B showed a NW-SE current as the more frequent current direction, parallel to the coast. Maximum current speeds of 35 cm/s occurred in March, with an average speed of 12 cm/s (Belmonte *et al*., 2001). Grow-out floating cages were octagonal with a capacity of 100,000 m^3.

The fish in both commercial farms were fed daily *ad libitum*, on small pelagic fish such as frozen herring *Clupea harengus*, round sardine *Sardinella aurita*, pilchard *Sardina pilchardus*, chub mackerel *Scomber japonicus*, Atlantic mackerel *Scomber scombrus*, bogue *Boops boops* and short-fin squid *Toradores sagittatus*.

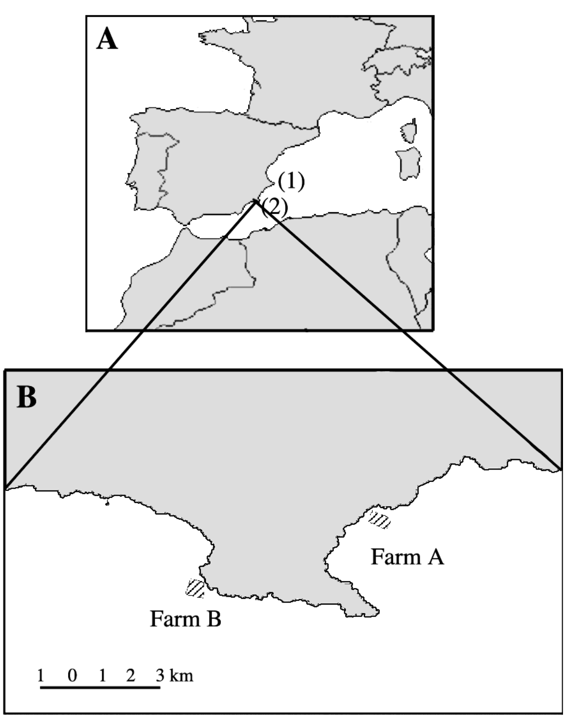

Figure 1. - **A**: Fishing area (1) Cabo de San Antonio; (2) Cabo de Palos. **B**: Geographical location of farm A and farm B. *[**A** : Aire de pêche (1) Cabo de San Antonio; (2) Cabo de Palos. **B** : Localisation géographique des fermes aquacoles A et B.]*

A total of 72 animals were sampled to test possible differences in fish fork length, weight, fat, protein and moisture during the fattening process. Curved fork length (FL) and weight data were collected from every tuna sacrificed during the study period, from June to December 1998. Several individuals that died from natural causes were sampled during the transfer from the towing cage to the grow-out cage. Due to the high value of entire animal and since muscle cuts decrease the value of animals aimed at the export market, proximate composition was estimated from fillets sampled at the caudal peduncle after its death. Samples were stored at -80°C until analysis.

Experimental design

Tuna were sampled from the two localities (farm A and farm B) at three fixed times over a six-month period. Twelve fish of each group were sampled on two random days in June during the transfer, then in September and in November.

Proximate composition analysis

The fat, protein and moisture of the red muscle obtained from the fillets were analysed by standard methods, described elsewhere (Ghaedian *et al*., 1997; Suvanich *et al*., 1998). The fat content was determined by solvent extraction using SOXHLET System HT6 extractor (Lee *et al*., 1996). The protein content was determined by a Kjeldahl technique and multiplying N by 6.25 (Method 24.028; AOAC, 1984). The moisture content was determined by measuring the mass of a sample before and after drying in an oven (Method 24.003; AOAC, 1984).

Data analysis

Data on length, weight, fat, protein and moisture were analysed using three-factor analysis of variance (ANOVA). For comparisons between farms (fixed factor) along the captivity time (fixed factor) fish were sampled on two random days of the month. The assumption of homogeneity of variances was tested with Cochran's *C* test. Data for percentage were arcsine transformed and data for fish weight were transformed by ln (x+1) with α = 0.05 (Underwood, 1997).

The linear model of sources of variance was defined as follows:

$$X_{ijkn} = m + F_i + T_j + D(T)_{k(j)} + F \times T_{ij} + F \times D(T)_{ik(j)} + \text{Residual}_{n(ijk)}$$

where F : farm; T : captivity time; D : sampling days.

When the test of analysis of variance was significant for any factor, the Student-Newman-Keul (SNK) test was applied (Underwood, 1997).

RESULTS

The mean fork length of the total bluefin tuna caught in Cabo de Palos and caged in farm A (FL = 222.2 cm) were significantly smaller than the mean of total fish caught in Cabo de San Antonio and caged in farm B, FL = 245.9 cm ($p < 0.001$). On the other hand, the structure of fish population showed a homogeneous shoal in farm A with the fish size distribution peak at around 265 cm fork length. The size of the tunas of farm B is more spread (Fig. 2).

Boxplots of the tuna fork lengths (FL) in sampled fish show that the medians and corresponding distributions for September and November were very similar. The distributions in September for farm A and in September and November for farm B display a peak around the median, which boxes, containing 50% of data, go approximately from 241 to 250 cm FL in farm A and from 203 to 250 cm FL in farm B. The values are lower in June than in all the other periods in both farms, 50% of the individuals displaying lengths from 173 to 214 in farm A and from 167 to 227 cm FL in

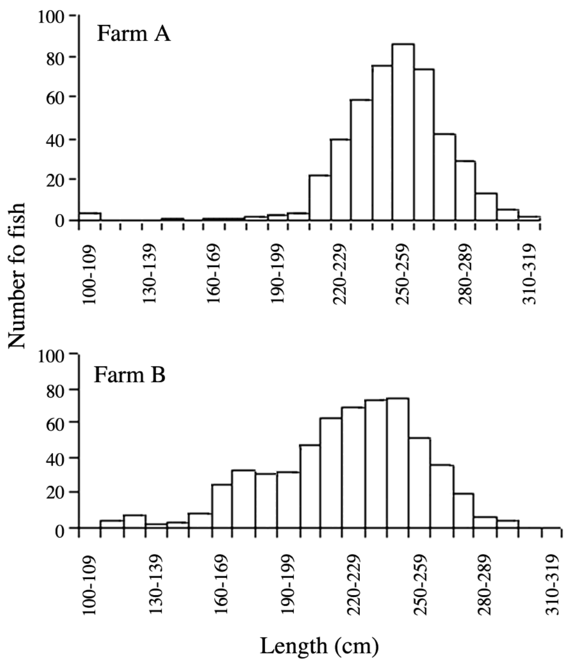

Figure 2. - Fork length frequency distribution (FL) of bluefin tuna *Thunnus thynnus* caged in farm A and farm B since June to December 1998. *[Distribution de la fréquence de la longueur à la fourche (FL) du thon rouge maintenu en cage dans les fermes aquacoles A et B de juin à décembre 1998.]*

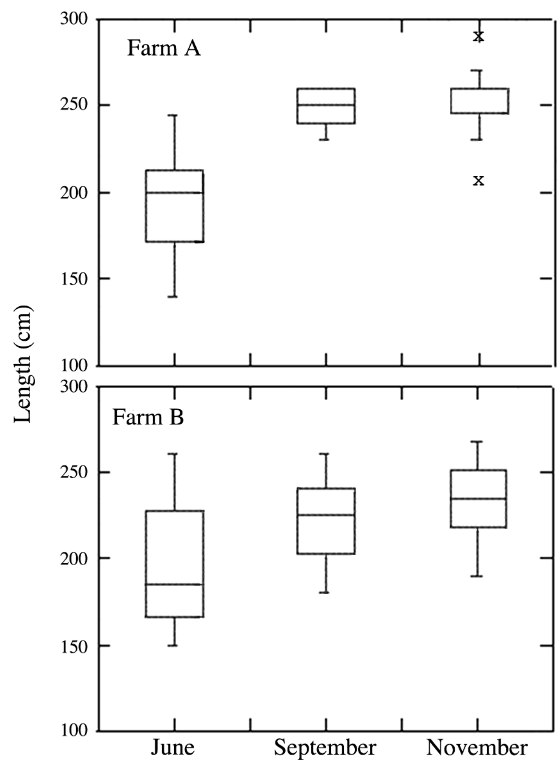

Figure 3. - Boxplot of sacrificed tuna fork length in each fish farm A and B for June, September and November. The box itself represents 50% of all cases, and extends from 25th to the 75th quartiles. The line inside the box shows the median. Points beyond the whikers (outliers) are drawn individually. *[Boîte à moustache de la longueur à la fourche des thons sacrifiés dans les fermes A et B en juin, septembre et novembre. La boîte représente 50% des cas et s'étend du 25e au 75e quartiles. La ligne intérieure représente la médiane. Les points extrêmes sont représentés individuellement.]*

Table I. - Results of variance analysis (three-way) of tuna fork length, weight and body composition. Df: degrees of freedom; MS: Mean Square; F: value of F statistic; ns: non significant; * p < 0.05, ** p < 0.01, *** p < 0.001. *[Résultats de l'analyse de variance (trois-voies) de la longueur à la fourche, du poids et de la composition du corps du thon.]*

		Fork length (cm)		Weight (kg)		Fat		Protein		Moisture	
Sources of variation	Df	MS	F	MS	F	MS	F	MS	F	MS	F
Farm = F	1	2688.89	4.79ns	1.99	15.26*	367.43	77.67**	4.74	25.49*	99.66	104.01**
Captivity time = T	2	11272.40	23.86*	1.48	15.71*	2268.60	548.00***	28.44	316.90***	468.98	309.62***
Sampling days= D (T)	3	472.44	1.16ns	0.09	1.01ns	4.14	0.58ns	0.09	0.26ns	1.52	0.74ns
F x T	2	3247.96	5.79ns	0.32	2.43ns	40.67	6.38ns	4.51	24.24*	12.34	12.88*
F x D(T)	3	561.05	1.37ns	0.13	1.40ns	6.37	0.90ns	0.19	0.54ns	0.96	0.47ns
Residual	60	409.01		0.09		7.11		0.35		2.04	
Transformation		None		Ln (x+1)		Arcsin		Arcsin		Arcin	

Farm A

Time	Length (cm)	Weight (kg)	Protein (%)	Fat (%)	Ash (%)	Moisture (%)
1	193.2 ± 12.5	140.7 ± 24.1	24.9 ± 0.3	2.5 ± 0.9	1.23 ± 0.02	72.1 ± 0.9
2	247.5 ± 4.7	299.2 ± 20.8	23.2 ± 0.5	15.7 ± 1.2	1.17 ± 0.08	61.1 ± 0.9
3	253.3 ± 8.2	303.9 ± 32.9	21.0 ± 0.3	22.4 ± 1.7	0.87 ± 0.02	55.9 ± 1.3

Farm B

Time	Length (cm)	Weight (kg)	Protein (%)	Fat (%)	Ash (%)	Moisture (%)
1	194.3 ± 14.5	131.4 ± 28.2	25.1 ± 0.5	1.6 ± 0.9	1.19 ± 0.03	72.9 ± 1.0
2	222.5 ± 9.4	206.3 ± 26.9	24.5 ± 0.3	8.9 ± 1.7	1.09 ± 0.02	65.5 ± 1.5
3	233.9 ± 9.6	202.3 ± 29.2	22.1 ± 0.4	15.6 ± 1.2	0.97 ± 0.02	61.7 ± 0.9

Table II. - Mean fork length (±SE), mean weight (C), and proximate composition (±SE) of fish sampled during three times of experimental period for both localities (farm A and farm B). *[Moyenne et erreur standard de la longueur à la fourche, du poids et de la composition globale des poissons échantillonnés au cours des trois prélèvements effectués dans les deux localisations (fermes aquacoles A et B).]*

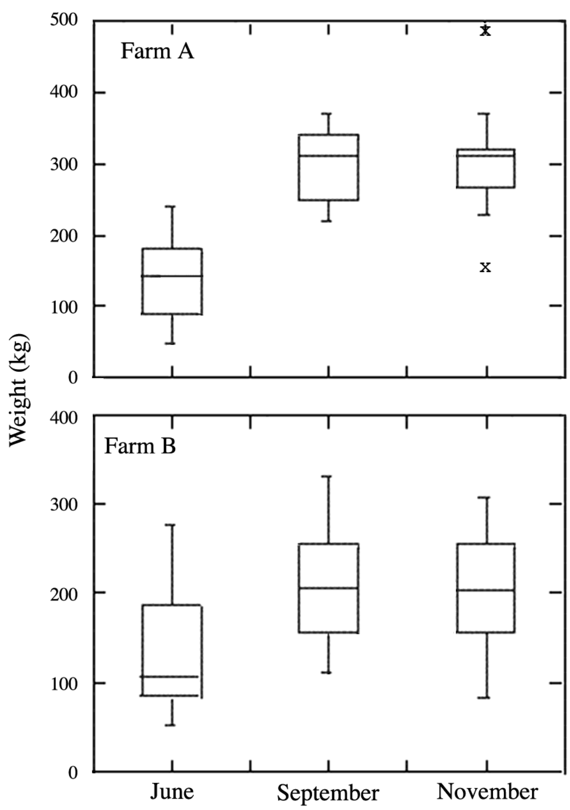

Figure 4. - Boxplot of sacrificed tuna weight in each fish farm A and B for June, September and November. The box itself represents 50% of all cases, and extends from 25th to the 75th quartiles. The line inside the box shows the median. Points beyond the whiskers (outliers) are drawn individually. n = 12. *[Boîte à moustache du poids des thons sacrifiés dans les fermes A et B en juin septembre et novembre. La boîte représente 50% des cas et s'étend du 25e au 75e quartiles. La ligne intérieure représente la médiane. Les points extrêmes sont représentés individuellement. n = 12.]*

farm B. The spread of their distribution was lower in September and November than the spread in June in both farms (Fig. 3). Means of tuna fork length were significantly different among the three periods ($p < 0.05$) but not so between farms (Tabs I, II). Fish sampled during June were significantly smaller (193.75 cm FL) than those sampled during September (235 cm FL) and November (243.63 cm FL) after 4 and 6 months in captivity, respectively (SNK test) (Fig. 3).

Boxplots of fish weight showed that the medians for September and November fish were similar for each farm (300 kg approx. in farm A and 203 kg approx. in farm B), but there existed differences in the distribution in farm A. In addition, the distribution of the boxes for farm B was similar. The box representing bluefin tuna weight for June was smaller than the box for September and November in both farms, corresponding to weights between approximately 93 and 197 kg in both farms (Fig. 4). The mean weight was significantly higher for those sampled from farm A than those from farm B ($p < 0.05$; Tab. II). Additionally, weight significantly increased over time, ($p < 0.05$; Tab. II). Fish sampled before captivity were smaller in weight than those maintained in captivity for 4 and 6 months (SNK $p = 0.5$) (Fig. 4, Tab. I).

Fat contents were significantly different between farms ($p < 0.01$; Tab. II) and times ($p < 0.001$; Tab. II). Fat concentration was consistently higher at farm A, and fat concentration increased from June to November at both locations (Fig. 5). However, protein and moisture concentration decreased significantly from June to November (Fig. 5), therefore lipid composition increased while protein and moisture concentrations decreased over the time (Fig. 5).

DISCUSSION

The significant augmentation of lipid composition observed in bluefin tuna (about 20% during six months of fattening) is due to their capacity to digest proteins and their high rate of food conversion (Graham, 1975). The lipid content measured in the fish caudal peduncle from animals during June in both farms is a little higher than those obtained by Establier (1963) from the mesenteric perigonadal of tuna collected by the traditional tuna trap "almadraba". This author found values of 1.33 ± 0.36% of lipids for the animals collected during the spawning migration into the Mediterranean Sea, whereas tunas collected during out-migration after spawning from the Mediterranean sea to the Atlantic had a 25.20 ± 2.00% of lipid contents (Establier, 1963). It has been reported that during the tuna migration to Mediterranean spawning grounds, the northern bluefin tuna

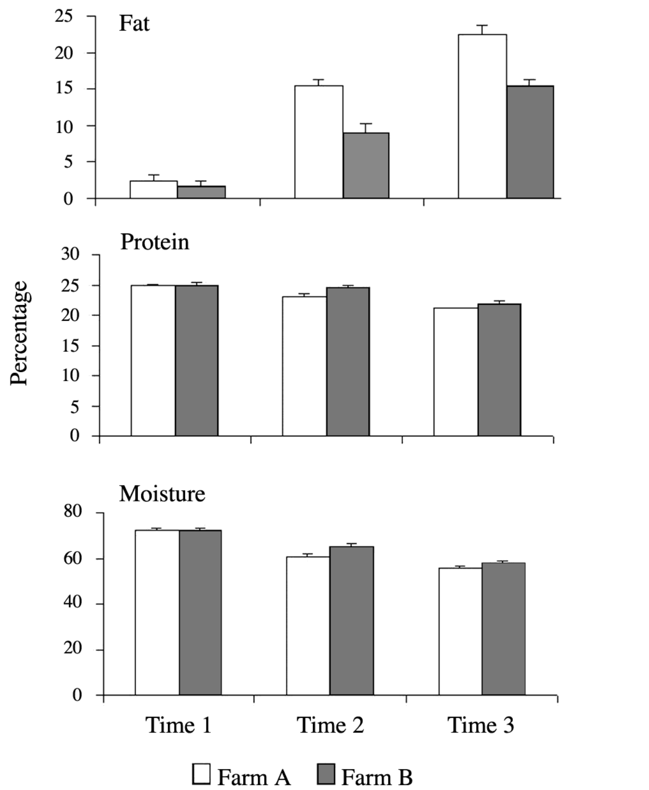

Figure 5. - Mean temporal changes in macronutrient composition of red muscle from caudal peduncle of bluefin tuna from the two locations fish farm. Data are mean and vertical bars represents the SE. n = 12. *[Variations en fonction du temps de la composition globale du muscle rouge du pédoncule caudal du thon rouge maintenu dans les fermes aquacoles. Les histogrammes donnent les moyennes et les barres verticales les erreurs standards.]*

do not feed considerably (Rodriguez-Roda, 1964), therefore the nutrients and energy required to produce mature eggs must be retrieved from reserves accumulated prior to the start of the journey. So, the fat tissue is, in fact, greater than two-fold more abundant in pre-spawning bluefin tuna from the Strait of Gibraltar than in spawning bluefin tuna collected around the Balearic Islands (Medina *et al.*, 2002). The data obtained in June correspond to the fish caught in the middle of the Mediterranean trip during the spawning period, when the fish had active gonadal development (Corriero *et al.*, 2003).

Mourente *et al.* (2001) suggested that the lipid from perigonadal fat depots are transferred to the gonad and catabolized to provide metabolic energy for the biosynthesis of gonadal constituents and the disappearance of muscle and liver depots is likely to be used for catabolism to provide energy for swimming during spawning migration. During the months studied for this research, fish with developed gonads had been observed during the first months in captivity. It is possible that lipid transfer to the muscle through gonad re-absorption accounted for some of the fattening observed during this project (pers. obs.).

Variations in fat levels between both localities could be due to various reasons, such as different environmental conditions: farm A had a lower current speed than farm B (Belmonte *et al.*, 2001). Differences in the hydrodynamic conditions could lead farm B animals to develop higher protein levels, as the greater swimming effort may result in an increase in muscle tissue generation. In this sense, it is important that this is kept in mind when selecting a farm location, as fish muscles with high oil content could be considered low quality by the sashimi market. Also, the high hydraulic flow facilitates waste dispersion from the farm, avoiding pollution and loss of water quality in the area (Ruíz *et al.*, 2001). Differences between farms can be the result of changes in the feeding protocol (food amounts, types of food fed, etc.), but both farms are from the same company with the equal managerial strategy of feeding administration. Fish density (farm A contains 126 fish more then farm B) could also contributed to the observed differences over the 6-month period.

All of the bluefin sampled during captivity had a similar average length of 239 ± 3 cm which represents 10-11 years old fish, known collectively as “giants” (> 196 cm fork length) according to some authors (Rodriguez-Roda, 1964; Labelle *et al.*, 1993). Animals sampled before caging were “large medium” bluefin tuna with an average length of 201 cm or the equivalent age of 8-years old and most of them had died from natural causes. Fishes actively assemble into elective group sizes, depending on, for example, food availability or migratory status (Hager and Helfman, 1991; Pitcher and Parrish, 1993). Also, during the fattening process the animals were sacrificed *ad hoc*, the farmer selected the number of animals to be sacrificed each day, but fish behaviour (hierarchic or feeding behaviour) determined which ones were sacrificed. Also, the physical environment (Holland *et al.*, 1990; Block *et al.*, 1997) or school structure (Partridge *et al.*, 1983; Lutcavage and Kraus, 1995; Hanrahan and Juanes, 2001) may play a role in determining the vertical position of tuna in the water column and animal priority order during feeding or leaving the cages, and that would explain why the size of fish caught during captivity was higher than the mean size population and the smaller animals were caught during in the last months of the study, December and January (unpubl. data).

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